AN

ESSAY

On the MYSTERY of

TEMPERING STEEL.

[Price 1s. 6d.]

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TEMPERING STEEL.

WHEREIN

The EFFECTS of that OPERATION
are fully conſidered.

Extracted from the Works of the celebrated
Monſ. REAUMUR.

By J. SAVIGNY.

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M.DCC.LXXI.

ESSAY

PREFACE.

THE desire of accounting for the effects of our own operations, is extremely natural; I have often been greatly mortified in not being able to assign any satisfactory reason to myself, why putting a piece of heated steel into cold water should occasion its becoming hard.

hard. I failed not to make enquiries wherever I discovered the least probability of obtaining information, and looked into every *English* author, from whose works I could form the least expectation of gaining any knowledge herein; but I found very few, even among the learned, who had attempted the explanation; and what those have delivered, whom I have perused, never failed rather to increase than remove my doubts, by making

making the myſtery ſtill more myſterious.

My diſappointments have ſometimes ſuggeſted to me, that it is better for an author to be perfectly ſilent on abſtruſe points, than to treat thereon, unleſs he poſſeſſes both intention and ability to be very explicit.

I found myſelf reduced to the neceſſity of attempting the diſcovery by my own experiments; and though I cannot ſay this

proved

proved an unpleaſing taſk, yet I muſt confeſs, it fell very ſhort of affording me the knowledge I was in ſearch of.

While I was engaged in this purſuit, I learned by accident, that a *French* author of great reputation had wrote upon the ſubject: having peruſed his works, I diſcovered a much more elaborate account of the matter, than any I before had met with. His thoughts ſeemed to be

be delivered without the leaſt diſguiſe, his reaſons ſupported by very ingenious experiments, and his writings through the whole appeared evidently calculated to inveſtigate the knowledge I had hitherto ſearched for in vain. I thought it but juſtice to give this account of my author, leſt the reader ſhould condemn in him, what, very likely, may be owing to the inability of the tranſlator.

I made no doubt, but every mechanic who had any concern in the myſterious operation of hardening ſteel, would be as well pleaſed as myſelf, to have any information on the ſubject, and, if they ſhould not receive, in peruſing the following extract, ſo much ſatisfaction as the original is capable of affording, I flatter myſelf however, they will herein find the matter more copiouſly diſcuſſed, than in any other author, and that, if it ſhould fail

of

of affording a thorough conviction, as to the ſubject treated of, it will, notwithſtanding, ſet it in ſuch a light, as cannot fail to aſſiſt thoſe, who may hereafter be in purſuit of the diſcovery. In this view, I ventured to hope the publication would ſtand excuſed, and that the propriety of the deſign would extenuate the defects of the production.

The operation by which ſteel is rendered hard, is of very an-

cient date, has been practiſed in almoſt all countries, by numberleſs artiſts of different denominations, and yet, I believe, I may venture to aſſert, that, even to this day, there is not, among the whole catalogue of nature's ſecret workings, any effect produced, whoſe cauſe is ſo little underſtood; I no leſs honour Monſieur *Reamur*, for the bare attempt to elucidate ſo profound a myſtery, than I admire the very

very great extent of his judgement.

I will not pretend to alledge however, that every reaſon advanced by him, carries ſuch a degree of conviction with it, as to leave the mind without a doubt, nor do I believe, that he himſelf entertained that opinion of his arguments, even experiments themſelves, however ſpecious in appearance, do ſometimes illude the mind, and betray us into

into concluſions, which have at other times been found to be fallacious, but it ſhould not appear wonderful, that the author of nature is capable of producing effects by means, which finite mortals cannot comprehend.

In all phyſical enquiries, our moſt determined concluſions have no other baſis than ſuppoſition, from thence we reaſon, from thence produce arguments, and from thence draw inferences; if

our

our conjectures are well grounded, the conſequences become indubitable, but it is not at all ſurpriſing, if, as we are totally uncertain in reſpect to primary cauſes, we ſhould ſometimes reaſon ourſelves (if I may ſo expreſs it) into error; I am ſure my author appears to be thoroughly aware of this, and therefore, I preſume, he took great pains to convince himſelf of the certainty of his hypotheſis.

I have only to regret, that he now makes his appearance, under the disadvantageous circumstance of being translated by a man, who never had an opportunity of leaving his native kingdom, to improve himself in the language, from which the following pages are collected.

AN

ESSAY

On the MYSTERY of

TEMPERING STEEL.

THE diſtinguiſhing character of ſteel, conſidered with reſpect to the offices it ſerves, conſiſts in the peculiar property it has of becoming hard by means of tempering; a property ſo very eſſential to many arts, that without it they could not be exerciſed, an infinite number of tools and machines owing

their uſe entirely to their hardneſs. When we conſider the ſimplicity of the proceſs, by means of which we are capable of giving ſteel ſuch a degree of hardneſs, at the ſame time conſidering the extenſive uſe it is of in the world, we ſhall not heſitate to place it, as *Rohault* has done, among the number of thoſe moſt worthy our admiration.

Several naturaliſts have attempted to explain this phænomenon; but, as thoſe attempts were made at a time when the nature of ſteel was not ſufficiently known, it is not ſurprizing, that their accounts ſhould have been unſatisfactory. They endeavoured to account for it, according to the eſtabliſhed ſyſtem reſpecting the general hardneſs of bodies,

which

which would by no means furniſh a ſolution of the preſent enquiry, as it will be found, by the manner in which I ſhall endeavour to explain it, that ſteel, in becoming hard, departs from a fundamental law in that ſyſtem, which ſuppoſes that bodies of a ſimilar nature are ſo much the leſs hard, as they have more ſize with reſpect to the ſame quantity of matter, becauſe, in this caſe, the parts being leſs united, cannot hold ſo well together. And it will appear, by the experiments which I have made, that ſteel never fails to increaſe in magnitude by means of hardening; or, to come nearer the truth, that tempering fixes in it that increaſe of magnitude which the fire occaſioned.

The whole of the myſtery of hardening ſteel, according to the general method, may be explained in very few words. A piece of ſteel is heated, and, becoming red, is ſuddenly plunged in cold water. This little proceſs is ſufficient to have given a conſiderable degree of hardneſs to the piece of ſteel, which, had it been left to remain and cool among the coals from which it received the heat, would have been ſtill in a ſoft ſtate, tender and yielding to the file. This is an indiſputable fact; notwithſtanding a mind (not pre-adviſed of the caſe) left to gueſs by which of theſe circumſtances the ſteel had acquired the greater degree of hardneſs, would be

tempted

tempted to pronounce in favour of the latter.

In the operation of tempering, we begin by giving a conſiderable degree of heat to the ſteel; we introduce in its ſubſtance innumerable particles of fire, which ſeparate and detach its parts, and, in a word, enlarge its dimenſions. In this ſtate it is precipitated into cold water: the water very ſoon puts a ſtop to the action of the fiery matter, which had penetrated the ſteel; hence a part of the augmentation which the fire had occaſioned, becomes fixed in the maſs, it being impoſſible it ſhould loſe what it had acquired, unleſs the parts could return to the place they firſt poſſeſſed; and that is prevented by the heat yet

retained

retained in the interiour parts, which cannot receive the ſame degree of coldneſs at the inſtant the outward parts are affected: hence it appears, that one of the effects produced by tempering of ſteel, is to give it a greater degree of magnitude than it would have had, had it been ſuffered to cool of itſelf.

Water is the only body which in becoming hard (as in the inſtance of ice) apparently increaſes in volume; but this appearance, according to a very nice experiment made by Monſieur *Homberg*, will be found to be illuſive, for he tells us, that, after having, with much time and pains, extracted moſt of the air contained in a quantity of water, he diſcovered that water in freezing always

decreaſed

decreaſed in bulk, and by this we may perceive, that what we before thought was occaſioned by the body's becoming hard, was in reality owing to nothing elſe than the dilatation of the air which the water contained.

If the enlargement of ſteel, occaſioned by tempering, ſhould not, by what has been ſaid, be ſufficiently proved, it will appear leſs doubtful by the examination of a piece of ſteel that is broke, after having been tempered, which will be found to be more porous than before; *

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* This aſſertion muſt, at firſt ſight, appear extraordinary; as thoſe who have hardened ſteel, never think that operation well performed, unleſs the grain of the ſteel appears to be much cloſer than that in a ſoft ſtate; but I believe, notwithſtanding, Monſieur *Reamur* is perfectly right; for

it

an experiment I have often tried will be a ſtill further conviction of this truth; which is, to meaſure the dimenſions of the ſteel before it is heated; and again, after it is hardened, when it will always appear to have gained ſome degree of magnitude; it has been obſerved by Mr. *Perrault*,

it will appear, by what he ſays hereafter, that though the body of tempered ſteel ſeems of a texture much leſs porous than the ſteel which is not tempered; its grain is, nevertheleſs, conſiderably larger, and its appearance of cloſeneſs is owing entirely to the fluid matter which the heat had diſperſed among its particles, and which became fixed in the interſtices of the grain, by the ſudden manner of cooling it; thoſe who doubt this, need only quench a piece of ſteel that is heated much more than common, and they will find the grain extremely coarſe; for the violence of the heat having driven the fluid matter from among its interſtices, the ſize thereof will then be very diſcernable.

Perrault, that a piece of ſteel wire, after being tempered, would not paſs through the ſame hole which it did before it was hard; this is what I have often tried, and have always found it prove the certainty of an augmentation: not, however, contented with this experiment, I was deſirous to know, if poſſible, with more preciſion, how great this augmentation might be; to this end, I procured a piece of iron hollowed, ſo as to receive a piece of ſteel ſix inches long, two broad, and half an inch thick; after having hardened pretty highly, the piece of ſteel, which I had made to fit with the utmoſt exactneſs in this iron caſe, I found it had gained in length the twelfth part of an inch, there was

alſo an increaſe in the width and thickneſs, proportionable to what it had acquired in length: this admitted; the diameter of the volume of ſteel hardened to a certain degree, will be in reſpect to the meaſure of that untempered, in the proportion of 145 to 144, conſequently the bulk of hardened ſteel to that which is not ſo, ſtands in a greater proportion than 49 to 48, for the cube of 145 is 3,048,625, that of 144 is 2,985,984, and the difference between one and the other is 62,641 (that is to ſay) ſteel in hardening, acquires at leaſt a 48th of its original ſize.

It is then ſufficiently proved, that tempered ſteel is of a texture more rare than that which is ſoft (i. e. not tempered.)

pered.) Now the cauſes which may be ſuppoſed likely to increaſe its hardneſs in augmenting its ſize, may be reduced to three; 1ſt, either the fire or water has added a matter to the ſteel, which occaſions the increaſe, and unites its parts better together; or 2dly, on the contrary, the fire has driven from within the ſteel ſome kind of matter, which prevented the parts from being ſo well united as they otherways might be; or laſtly, ſome changes have been occaſioned in the body of the ſteel in the figure, or in the arrangement of its parts, by means of which thoſe very parts obtain a better ſituation.

I attempted thoſe experiments which I judged moſt likely to afford me in-

formation to which of theſe cauſes the effect might be aſcribed; I was ſoon convinced that the firſt and ſecond were to be utterly rejected; the firſt is not conſiſtent with reaſon; the only matter which could inſinuate itſelf into the ſteel during the inſtant of tempering, is water; now it does not appear poſſible, that the water could find a paſſage to penetrate through the ſteel; and moreover, water does not ſeem to be of a nature well adapted to occaſion the hardneſs of ſteel; it is neceſſary for this purpoſe to have the addition of ſome matter, whoſe parts ſhould be united in a ſtronger manner: I am now going to mention an experiment which might have rendered the foregoing ar-

guments

guments unneceſſary, and which will prove, that the augmentation which ſteel acquires, is not owing either to the introduction of water, or any other weighty ſubſtance.

I weighed in a very exact manner a piece of ſteel, which I reduced preciſely to an ounce, and after having heated it to a full red, I quenched it in cold water; taking it thence, I wiped it quite dry, and weighed it again, when I found, not only that it had not gained any weight, but that it had even loſt half a grain. Now it muſt be obſerved, that if the increaſe of its ſize was occaſioned by the introduction of any ſubſtance, of an equal weight with itſelf, the piece of ſteel ſhould have acquired a forty-

eighth

eighth of its original weight, in conſe-quence of having gained that in its ſize, as before mentioned, now if the acquired capacity of the ſteel had even been filled with parts of water, in that caſe, the increaſed weight would be very deter-minable, if conſidered in the proportion of weight, which that body bears to that of ſteel; again, if the introduction of water had any part in the hardening of ſteel, we may infer, that it would be-come ſtill harder by being tempered in boiling water, as then the heat of the water would doubtleſs facilitate its own penetration; and yet we are well con-vinced, that boiling water will not give ſo great a degree of hardneſs to ſteel, as that which is perfectly cold; it is

then

then pretty certain, that it is not by the introduction of any weighty ſubſtance, that ſteel in tempering, acquires an increaſe both of ſize and hardneſs; the loſs of the half grain as mentioned, might poſſibly ariſe from ſome ſmall flakes, which the heat had occaſioned to fall from the ſteel, notwithſtanding I took every precaution to prevent it, this is a circumſtance however ſcarce worth attention, for the loſs of ſo ſmall a part as half a grain, is hardly to be conſidered as any loſs at all.

What has been ſaid in oppoſition to the introduction of water, will have the ſame force againſt that of the particles of fire, which it may be imagined remained confined in the ſteel, when the

water

water in cooling it, cloſed the pores of its outward ſurface; for in this caſe alſo, there muſt have been an increaſe of weight; it follows then, that during the inſtant of tempering, no matter whatever can enter the ſteel, unleſs it be of an impalpable and ſubtle nature.

In reſpect to the ſecond explanation; I mean that which makes the hardening of ſteel depend on a matter, which the fire forces from amidſt its particles, and to which the water prevented a return; I muſt own, this ſeemed at firſt very conſonant to my own manner of thinking; it appeared natural enough, to conceive there might be air confined amidſt the particles of untempered ſteel, and that this air tending to ſeparate the

parts,

parts, might in ſome meaſure oppoſe their adheſion; but that the fire in rarifying the ſteel, expelled this air from among its particles, the return of which was effectually prevented, by the ſudden manner of cooling it, though it would again have entered the ſteel, little by little, had it been ſuffered to cool by degrees; but leſt any one ſhould adopt this notion, as I myſelf was tempted to do, I will mention an experiment, which convinced me of its fallacy. I contrived means, after having given a very ſufficient heat to a piece of ſteel, to let it cool in a ſpace free from air; now the reader will readily conceive, that if the hardneſs of ſteel was occaſioned by means of preventing the re-entrance of air, ſteel

cooled in this manner, ſhould be as hard as when quenched in water, the circumſtances with reſpect to their effect, being pretty near the ſame. I will not enter into a minute relation of every article of management I uſed on this occaſion, it is ſufficient to ſay, that the tube in which the ſteel was laid to cool, was ſo effectually ſtopped, (after having been rarifyed within) as to prevent the communication of any outward air; having repeated this experiment ſeveral times, I always found that the ſteel was juſt in the ſame ſtate, as it would have been had it cooled in the open air.

Since then the hardneſs of ſteel is not produced, either by the introduction of a new matter, or by the expulſion of

air,

air, we muſt therefore ſearch for the cauſe in the alteration, which its texture undergoes; in this light, both *Rohault* and *Perrault*, believed they had made the diſcovery; the firſt inſiſts, that the texture of ſteel is rendered more uniform by tempering, on account, that the water puts a ſtop to the action cauſed by the fire, at an inſtant, when the parts were nearly in a ſtate of fuſion, and that theſe parts have not time therefore to unite themſelves, ſo as to become larger, and thereby leave certain intervals in the ſteel, wherein the teeth of a ſaw, or thoſe of a file, might eaſily engage; but probably this author never had ſufficient opportunity to examine tempered ſteel, after it had been broke, or he

would certainly have obſerved, that the higher ſteel is tempered, the more its grain is enlarged, and the greater the ſpace of diviſion is between each grain, the more alſo it is hard; if then ſteel becomes harder by being quenched in water, it is not therefore that the ſpace between its parts are ſmaller, but that in reality each grain is become in itſelf more hard, and that the parts of each grain are better united.

Perrault has acknowledged, that the grains of ſteel became harder by tempering, notwithſtanding the operation left intervals between them; he attributes this hardneſs of the grains, to the preſſure of a ſubtle matter, which he admits to be the general cauſe of hardneſs

in bodies, and is of opinion, that the ſudden manner in which ſteel is cooled by tempering, ſerves to encloſe this matter; if this was the caſe, the matter thus confined, would have its liberty to eſcape, and doubtleſs would do ſo, when the piece of ſteel was broke, and the broken ſurface then ſhould become ſoft in an inſtant, but we find on the contrary that it always preſerves its hardneſs; the manner in which he ſuppoſes a ſubtle matter to act herein, is as unſatisfactory in this particular, as it is when conſidered as a general cauſe; it is no eaſy matter to content Philoſophers on this important queſtion.

Independent of any general cauſe of hardneſs, I believe it will be poſſible to

diſcover

diſcover the occaſion of the hardneſs of ſteel, by means of the aſſiſtance I have derived from the examinations I have made into the nature of that metal, an account of which has been heretofore delivered to the Royal Academy at *Paris*; we ſhall thereby be able to conceive the reaſon why the action of tempering has ſo great an effect upon ſteel, in proportion to what it has on iron; and this, we find, cannot be accounted for according to Mr. *Perrault*'s explanation.

It is well known, that the principal difference between iron and ſteel is, that the latter is very conſiderably more impregnated with particles of ſulphur and ſalt, than we find the other to be.

Now

Now it ſeems moſt reaſonable to ſuppoſe, that wherein we find theſe two bodies to differ from each other, we may there expect to find the occaſion of that difference which the ſame treatment produces in each; it muſt be then owing to the ſulphur and ſalts, which the ſteel poſſeſſes in greater quantity than the iron, by which it acquires the property of becoming hard. I ſhall endeavour to explain in what manner it may occaſion the ſteel to become hard, when it is cooled ſuddenly, and why, on the contrary, it leaves it ſoft, when it is ſuffered to cool by ſlow degrees.

It is neceſſary to remember, that both iron and ſteel have an aptneſs to imbibe

bibe ſulphur as they acquire heat, but that too violent a heat may again deprive them of it: for the preſent, to avoid as many unneceſſary circumſtances as poſſible, let us take under conſideration one ſingle grain of ſteel, which has not been tempered. This grain may be diſcovered to be no other than a collection of other grains, which we will here term the molecules. Theſe molecules are diſcoverable by the microſcope, and appear themſelves to be compoſed of other parts, which we will ſuppoſe are of an elementary nature. To carry our ideas ſo far as the ſubject would permit, we might ſtretch this diviſion much further; but it may be ſufficient for the preſent purpoſe to let it reſt here;

here. We have then under our conſideration a ſingle grain of ſteel, the molecules it is compoſed of, and the elementary parts of thoſe molecules. Now, in expoſing to the fire the piece of ſteel which contains the grain, (at preſent the object of our conſideration) we ſhall find, that the ſulphur and ſalts, contained in the molecules, will be ſooner melted than the molecules themſelves, and are by the heat drove from among the parts in which they were contained, and take place amidſt its vacancies. Thus the matter, which the heat had expelled from within the molecules, now fills up the ſpaces between them: it is pretty evident then, that, when a grain of ſteel has received

a certain degree of heat, the vacant ſpaces of the molecules, of which it is compoſed, are in part filled up by a ſulphurous matter, which they did not before contain, and which has been extracted from the molecules themſelves. In this ſtate the piece of ſteel, which contained the forementioned grain, is ſuddenly plunged in water, and, in that inſtant, we fix at once the ſulphur and ſalts, which were in a ſtate of fuſion, and thereby depriving them of their fluidity, they are no longer in a condition to re-enter the cells, from which they were drove. Thus the ſmall interſpaces of the molecules are better filled up, and by a matter which we may ſuppoſe almoſt as hard as we pleaſe.

The molecules of this ſingle grain, therefore, will hold better with each other, and the grain of ſteel will be more difficult to divide or break; or, (what is the ſame thing) the grain is become more hard. The ſame effect, doubtleſs, muſt have been produced to all the other grains contained in the piece of ſteel, which received the ſame degree of heat, and thus the whole body becomes hard.

The pyrites, which is a ſort of ſulphurous ſtone, well known among naturaliſts, inclines us to believe, that parts of ſulphur and ſalt mixed together, may have a conſiderable degree of hardneſs, it being acknowledged, that the pyrites is, in itſelf, hardly any thing more than

ſalt and ſulphur; and yet, notwithſtanding, it is ſo very hard, that it was formerly made uſe of for many purpoſes, to which iron is now appropriated. When I ſpeak of the ſulphur natural to iron and ſteel, I would not be underſtood to mean that of a pure and ſimple nature: on the contrary, I conſider it as a ſort of common ſulphur, like unto that of the pyrites, which is known to contain a great quantity of ſalt.

But, admitting the ſulphurous matter, we have been ſpeaking of, had a leſs degree of hardneſs than what we ſuppoſe it to have, it cannot, however, (by filling up the intervals of the molecules)

fail

fail of uniting them better together; and it appears very certain, that the hardening of ſteel is produced by means of fixing a fluid matter, which flows among the interſtices of its parts, and which is not of a ſimple nature, but is, doubtleſs, ſtrongly impregnated with particles of ſalt.

Nothing can ſerve better to explain, and at the ſame time confirm, what has been ſaid, than the manner of tempering ſteel or iron, by incloſing either in an iron box, together with ſuch ingredients as will beſt ſerve the purpoſe of producing more than an ordinary hardneſs; ſuch, in ſhort, as abound moſt with ſulphurous and ſaline mat-

ter.

ter *. Theſe are ſet in fuſion by the heat, and, entering the ſteel, fill up not only

* This operation is termed, by thoſe who perform it, caſe-hardening, and with much reaſon, as the thing which is to be hardened, is heated in a caſe, uſually made of iron. The ingredients commonly incloſed to aſſiſt the proceſs, are ſhreds of worn leather, pieces of horn, ſoot, &c. Theſe ſubſtances, which contain a great quantity of the ſulphurous matter, being heated for a certain length of time, are deprived of that matter by the piece of iron which they encompaſs, and which, according to the *French* author, has a natural thirſt to imbibe ſuch. When it is judged that the heat has been ſufficient to produce the effect, the thing intended to be made hard is taken out and quenched in water, and it is then found to be as reſiſtable to the file as even ſteel. It muſt be acknowledged, that this circumſtance is greatly in favour of our author's doctrine, it being hardly poſſible to conceive a ſtronger proof of the certainty of his hypotheſis.

This

only the interſtices, but alſo the molecules themſelves. In this ſtate it is taken from out the box, and quenched in water, and by this means it will become harder by the ſame degree of heat, than if it had been heated in the common manner. Our explanation aſſigns the reaſon for this difference, and the difference, at the ſame time, confirms our explanation; for the grains of ſteel, thus incaſed, and thus ſupplied, are more penetrated with ſulphur and ſalts, than thoſe which are heated directly on the coals; and by being cooled ſuddenly, more of thoſe matters

This proceſs, however, is commonly uſed with iron only, ſteel being capable of receiving a ſufficient degree of hardneſs by the methods ordinarily practiſed for that purpoſe.

matters conſequently become fixed in the ſteel, in the one caſe, than in the other. This method uſed, even with iron, occaſions a hardneſs about its ſurface, approaching to that of ſteel; the reaſon of which is very obvious, for, during the time it was heating, the interſtices were filled with the ſulphurous matter in which it lay, and that matter being fixed on the exterior parts, by being quenched in water when in a ſtate of fuſion, occaſions a degree of hardneſs nearly equal to that of ſteel.

There is, however, a difficulty, which ſeems to occur, *viz.* That the means by which ſteel becomes hard, ſhould, at the ſame time, render it brittle, and

more

more eaſy to ſeparate than untempered ſteel. This appears neceſſary to allow, when we conſider, that in ſtretching two pieces of ſteel of equal diameters, the one tempered, and the other not, the piece which is hard will break by a leſs degree of force than the other. To explain which, it muſt be remembered, that as ſteel increaſes in ſize by tempering, without the addition of any metallic body to occaſion that increaſe, the number of points therefore which come in contact, are leſs in ſteel, after tempering, than before; conſequently, the whole of the ſteel is, in one ſenſe, weaker after being hardened than before. It ſeems, however, difficult to admit, that tempered ſteel, which reſiſts

incomparably more to the file, ſhould be weaker when extended, than ſteel which is not hard; for, notwithſtanding that ſteel becomes fragil by tempering, yet that does not, however, ſufficiently prove, that the junction of its parts ſhould be weaker. The ſtroke of a hammer, for example, which will break a piece of thick glaſs, will not do the ſame to a piece of ſtraw; but the ſame piece of glaſs ſuſpended will ſupport a conſiderable weight, and the ſtraw only a light one.

To be more certain on this head, I had recourſe to an experiment. After having tempered part of a piece of ſteel wire, and marking that part which received the greateſt degree of heat, I

fixed

fixed one of the ends, and to the other hung a conſiderable weight, which I increaſed till the wire broke aſunder. Having repeated this experiment ſeveral times, I conſtantly found the fracture happen in the part which was hardened, and generally where it had partook of the greateſt heat, and which conſequently was the hardeſt. I repeated this trial ſo often, and with ſo many precautions, as left me without a doubt concerning it. It is not eaſy to aſcertain how much the force neceſſary to break a piece of tempered ſteel in this manner, is leſs than what is required with ſteel that is not tempered; but, I am convinced, the difference is very conſiderable, and much more than

might be expected, in proportion to the augmentation it acquires in ſize.

Thus, by the very means, the ſteel acquires a property to reſiſt friction or preſſure, it becomes more fragil, hence there appears a kind of compenſation, which gives it in one ſenſe what it looſes in the other.

Notwithſtanding the grains of ſteel themſelves do hold leſs powerfully together after being tempered than before, it might, nevertheleſs, be expected they would reſiſt more to the file or chizel, as we find is the caſe, becauſe the parts of which each grain is compoſed, are in themſelves much better united than before tempering. When a file acts upon a piece of ſteel, it does not take away

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the grains entire, as will appear by viewing the ſurface of ſteel that has been broke aſunder, which, however, even and cloſe, ſtill diſcovers much more ragged particles than the ſurface of ſteel that has been filed, which is a ſufficient proof that the ſeparation happened between the grains, and not in the grains themſelves; a chizel, likewiſe, cannot cut ſteel without dividing the grain, it can hardly be ſuppoſed to direct its way preciſely between two grains; thus, the better united the parts are, which compoſe the grain, the more they will reſiſt to the file or chizel, which are the methods commonly uſed to prove its hardneſs.

Notwithſtanding

Notwithſtanding hardened ſteel may be weaker in one reſpect than the ſteel which is ſoft, its grains may, nevertheleſs, have a more powerful adheſion with each other, although it muſt be allowed that the amount of force, upon the whole, is leſs in ſteel which is tempered, than in that which is not ſo; to render this ſtill more clear, it is neceſſary to remember that it has already been proved that ſteel enlarges by being tempered; this enlargement ſuppoſes an increaſe of magnitude in each grain, and we will here deſire the reader to figure to himſelf two pieces of ſteel of equal ſize, the one tempered, the other not; in the former he will find the grain larger, and conſequently

not

not ſo numerous as in the other; the parts, therefore, which come in contact in the tempered ſteel, will not be ſo many in number as in the piece that is not hard, and conſequently, not having ſo many points of hold, will be eaſier cauſed to ſeparate; but notwithſtanding the weakneſs of its force, conſidered collectively, we may, however, eaſily imagine that it would be more difficult to ſeparate one of the grains from its neighbour, in the piece tempered, than in that which is not tempered, for the increaſed ſize of its grain occaſions it to have a greater ſpace of contact with the adjoining one, though the contact, not being ſo often repeated in the ſame degree of ſpace, leaves tempered ſteel,

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upon the whole, much more fragil than that which is ſoft; and it will always appear, that the larger the grain of ſteel is after hardening, the greater will be its degree of hardneſs.

Thus every phænomenon regarding the tempering of ſteel, is ſufficiently accounted for, we perceive the reaſon why ſteel becomes hard by tempering, why it becomes harder by being tempered hotter, and alſo why it happens to be leſs yielding, and more brittle after tempering; this conſequence indeed, might well be expected from the circumſtance of its augmentation, for in bodies of the ſame matter, and equal quantity, that will always be the moſt flexible, which is compoſed of the ſmalleſt parts; a cylinder of glaſs,

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for example, will be very brittle, and yet the ſame glaſs drawn into threads, will form a ſkaine of a very flexible nature, and the more ſo, as the threads of which it is compoſed are ſmaller. Untempered ſteel may be compared to the maſs formed of the ſmalleſt parts, and that which is tempered, to the other.

It remains to examine, why ſteel which has been hardened, will again become ſoft by being heated, or (which is the ſame thing,) why it would have remained ſoft, if inſtead of being plunged in water, it had been left to cool among the coals, from which it received the heat.

It has already been remarked, that both iron and ſteel have an eagerneſs to imbibe the ſulphur and ſalts, which the

heat cauſes to float in thoſe bodies, and by degrees, as the action of the fire grows weaker, part of the fluid matter, which had been forced from the molucules re-enters, if the heat diminiſhes by very ſlow degrees, the greater quantity will return, thus, the more the means of cooling the ſteel are procraſtinated, the leſs it approaches that ſtate, which tempering would have brought it to, on the contrary, the more ſudden the means are of cooling it, the harder it will be.

Notwithſtanding, we have all along ſpoke of tempering, as a very ſudden operation, it muſt not however, be conſidered as inſtantanious; neither ſteel nor iron becomes cold immediately, upon their being plunged in water, on the

contrary,

contrary, they preſerve a conſiderable heat for ſome time, and if the piece that is tempered, is pretty ſubſtantial, we may perceive that it retains its redneſs for ſome time, under the water, and during the ſpace the ſteel is undergoing the change, from a ſoft body to a hard one, it is eaſy to conceive, that part of the ſulphurous matter, which the fire had ſet in agitation, regains the place from whence it had been drove.

It may happen (according to the difference of ſteel) that, that which is tempered, after having been made white hot, may not have more ſulphur diſperſed in its parts, than other ſteel which is only heated red; this laſt remark explains a fundamental rule, reſpecting the

different degrees of hardneſs, ſteel may receive by tempering, *viz.* that of different pieces of ſteel tempered at the ſame degree of heat, that will always be the hardeſt, whoſe parts contain the greateſt quantity of the ſulphurous, and ſaline matter.

FINIS.